Study on the wettability and self-cleaning of butterfly wing surfaces

G. Chen, Q. Cong, Y. Feng & L. Ren
Key Laboratory for Terrain-Machine Bionics Engineering, Ministry of Education, Jilin University, Changchun 130025, P. R. China

Abstract

Many biological surfaces are hydrophobic because of their complicated composition and surface microstructure. Butterflies were selected to study their characteristics by Confocal Light Microscopy, Scanning Electron Microscopy and Contact Angle measurement. The contact angle of the water droplets on the butterfly wings surface consistently measured to be more than 140^o. The dust on the surface can be easily cleaned by moving spherical droplets when the inclining angle is larger than 3°. It can be concluded that the butterfly wing's surface possess a water-repellent, self-cleaning, or "Lotus-effect" characteristic. Contact angle measurement of the wings' surface with and without squamas showed that the water-repellent characteristics are a consequence of the microstructure of the squamas. Each water droplet (diameter 2-3 mm) covers 30-50 squamas each with a size of 40x80 microns. The regular riblets with a width of 1000-1500 nm are clearly observed on single squama. Such a nano-structure should play a very important role in the self-cleaning character.
Keywords: butterfly, hydrophobic, water-repellent, self-cleaning, Lotus-effect.

1 Introduction

The water-repellent characterizations of biological surfaces are due to their special surface composition and microstructure [1]. Many surface characterizations can be described as the result of macroscopical surface roughness, which is constructed from many kinds of microstructures.

For example, the some surfaces are hydrophobic nano-structure being cleaned by moving water, which is called the "Lotus-effect" by some papers [2]. This kind of surface is also called self-cleaning surface [3].

Design and Nature II, M. W. Collins & C. A. Brebbia (Editors)

After the butterfly emerges from its chrysalis, the wings cannot grow or change any more. They also cannot self-repair if the wings are damaged or destroyed. In order to reduce the influence of wind, rain, fog, dew and dust, the butterfly wing's surface has evolved to have water repellent and self-cleaning capabilities. Most butterfly wings surfaces are smooth at the macroscopic view, except that some body hair can be observed. But with the help of the microscope, we can find that the surfaces are composed of squamas and non-smooth, which is a so-called biological non-smooth surface. This kind of surface has special characteristics, lotus-effect and self-cleaning being one of them.

In this paper, the butterfly wings surface were studied by using the Confocal Light Microscopy (CLM), Scanning Electron Microscopy (SEM) and Contact Angle Measurement equipments. The wettability and the microstructure of wings surface were analyzed.

2 Experiments and methods

2.1 Material and preparation

The butterflies were collected from the parks in Changchun city, P. R. China. The samples were taken from the butterfly wing in rectangular segments of 10x20 mm. The upper side is defined as the upper surface when butterfly flying. To obtain an even surface, wings were affixed to glass slides with double-sided adhesive tape. Since it is very difficult to determine the exact contact angle and micro-image in hairy and bristle parts of wing, were cut out.

2.2 Contact angle measurement

The wettability of wing-surface was determined by measuring the static contact angle of a water droplet (2-3 mm diameter) using JC2000A Interface Tension/Contact Angle Measure Equipments (Powereach, China). The experimental temperature is 20 ℃.

2.3 Microscopy

The Confocal Light Microscope (XTJ-30 Stereo Microscope, Beijing Tech Instrument Co. Ltd) was used to acquire butterfly wing surface photographs with milimeter or micrometer dimensions sequence.

The investigation of wings were carried out with a SEM (JSM5310, JEOL LTD. , Japanese). The samples were cut into 5×5 mm in size and samples from each species were cut two pieces -one for the measurement of upper side and another for backside. All the specimens were affixed to copper with double-sided adhesive tape, and gold coated in the surface.

Design and Nature II, M. W. Collins & C. A. Brebbia (Editors)

Table 1: The contact angles of butterflies wing.

Name	Contact Angles	Contact Angles without Squama
Everes argiades hellotia	Up 141°/Down150°	
Polygniac-album	Up 151°/Down150°	
Polygniac-aureum	Up 153°/Down149°	96°
Childrena zenobiu	Up 152°/Down153°	
Vanessa indica	Up 152°/Down150°	
Vanessa cardui	Up 152°/Down150°	99°
Colias erate	Up 146°/Down152°	100°
Pieris rapae	Up 148°/Down147°	
Pontia daplidice	Up 151°/Down150°	100°
Gonepteryx mahaguru Gistel	Up 150°/Down153°	
Coenonympha amaryllis	Up 144°/Down145°	

3 Results and discussion

3.1 Characterization of the contact angle

The butterfly belongs to Lepidotera Pterygota Insecta. This phylum contains 12 Families, and their are 7 Families in the Jilin province, P.R.China. We acquired 4 Families, 11 Species butterfly samples [5] for this paper (Table 1).

Figure 1: Two water droplet on the butterfly surface.

In figure 1, we can find that 4-5 mm diameter water droplet can stay on the wings surface and keep its shape as a spherical droplet, and they were found to flow easily on the surface. The contact angle of the droplets consistently measured more than 140^{o} on both sides of the wings. This means that the butterfly wings are very excellent water-repellency, self-cleaning, or "lotus-effect" surfaces.

Design and Nature II, M. W. Collins & C. A. Brebbia (Editors)

Figure 2 descripts the method of measurement self-flowing angle by inclining the butterfly wing surface. The water applied to the intact surface forms spherical droplets that roll off the surface, the self-flowing angle is obtained at about 3°. In this case, we can say also that the butterfly wing surfaces are "water-repellent".

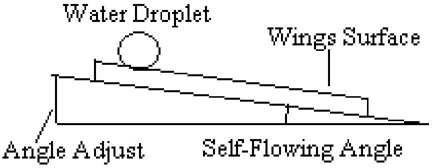

Figure 2: The experiments mode of measurement self-flowing angle.

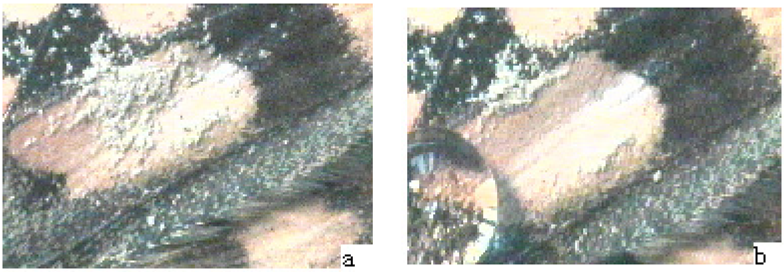

Figure 3: Photograph by the Confocal Light Microscope. a) Some dust on the wing surface. b) The moving spherical water droplet can clean the dust on the wings surface.

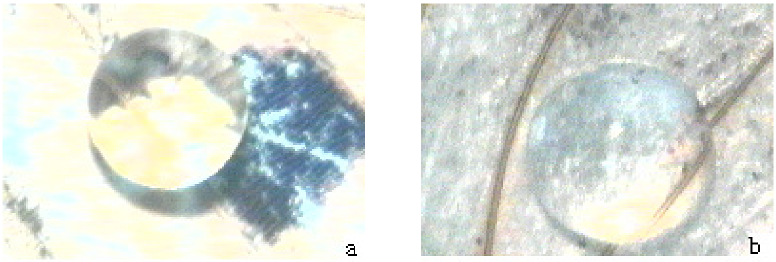

Figure 4: The Confocal Light Microscope photographs of water droplets on the original butterfly wings surface with a), and without squamas b).

Figure 4(a) shows a Confocal Light Microscope photograph of water droplets on the original butterfly wings surface, where it assumes a perfect spherical form. As a comparative experiment, the squamas on the butterfly wing's surface were cut out, and then the same amount water was placed on the surface. It is easy to see that the diameter of water droplet becomes larger, and this result is confirmed by the results of contact angle measurement (see table 1).

Design and Nature II, M. W. Collins & C. A. Brebbia (Editors)

We can conclude that the water-repellent, self-cleaning, or "Lotus-effect" character of butterfly wings surface are due to the characteristic and micro-structure of the squamas.

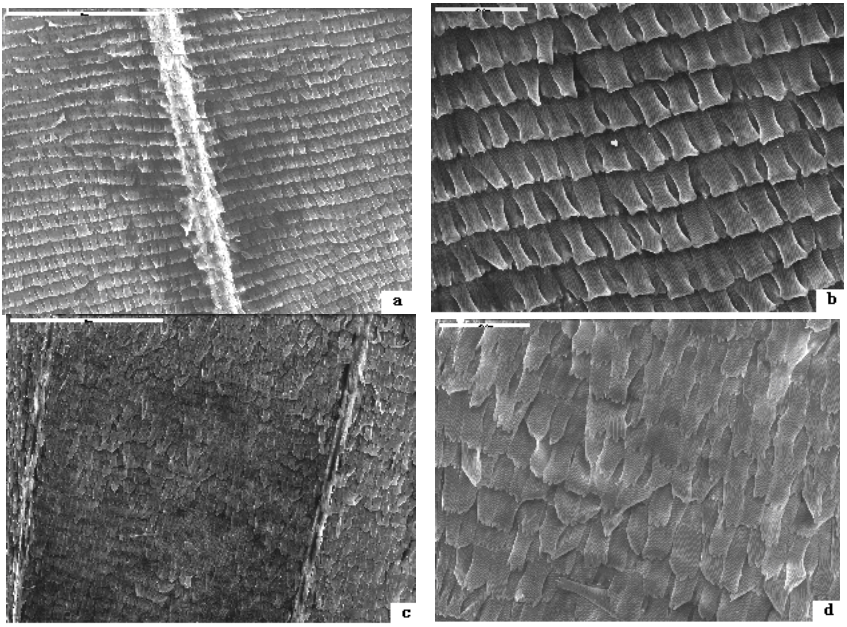

Figure 5: The SEM photographs of butterfly (Vanessa Cardui) wings surface up-side (a,b); and down-side (c,d); Bars in a and are 1 mm; in b and d are 200 micrometer.

3.2 Microstructure of squamas

Figure 5 are the SEM Microscope photographs of butterfly wings surface upside (a,b); and down-side (c,d). On the both side, the squamas are clearly observed with the size of 40x80 microns and 10-20 microns space. Each water droplet (diameter 2-3 mm) covers 30-50 squamas.

Figure 6 gives a SEM image of single squama on the butterfly wing's surface. The regular riblets with the width of 1000-1500 nm are clearly observed. Such nano-structure should play a very important effect on the self-cleaning character. Figure 7 shows the SEM photographs of a butterfly wing's surface without squamas, here no clear microstructure can be observed. Thus we can say that the water-repellency character in butterfly wing's surface not only depend on the existing of squamas but also depend on their microstructure. The detail experiments and description of nano-structure of wings surface and its relationship with its water-repellent properties is on going.

Design and Nature II, M. W. Collins & C. A. Brebbia (Editors)
 ISBN 1-85312-721-3

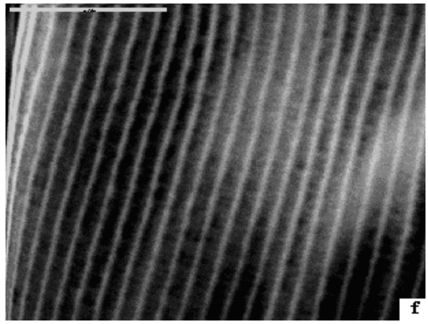

Figure 6: The SEM photographs of single squamas on the butterfly wings surface. Bar is 10 μm.

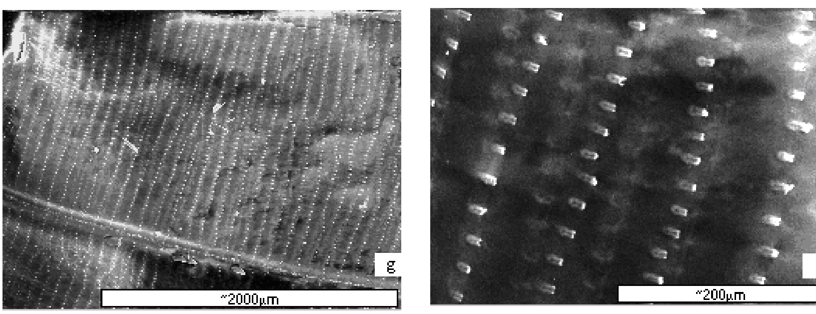

Figure 7: The SEM photographs of butterfly wings surface without squamas.

Acknowledgments

The project is supported by the Excellent Young Teachers Program of MOE, , Innovate Program of Jilin University (2001CX015), and the National Key Grant Program of Basic (Grant No. 2002CCA01200) of P.R. China.

References

[1] Barthlott, W.; Neinhuis, C. "Purity of the sacred lotus, or escape from contamination in biological surfaces", *Plantar* 1997, 202, 1~8

[2] Neinhuis, C.; Barthlott, W. "Characterization and Distribution of Water-repellent, self-cleaning Plant Surfaces", *Annals of Botany* 1997, **79,** 667~677

[3] Barthlott, W. "The Lotus-effect: nature's model for self-cleaning surfaces", *ITB International Textile Bull*. 2001

[4] Cong, Q.; Ren, L. Q.; Chen, B. C.; Yan, B. Z. "Using Characteristics of Burrowing Animals to Reduce Soil-tool Adhesion ", *Trans of American Society of Agricultural Engineers* 1999, **42,** 1549-1556

[5] Yu, W. Y. "The Simple Methods of classing 12 Families of Chinese Butterflies", *Journal of Nanjing Normal College*, 1997, **13**, 66-70
[6] Sun, J. Y. "Geometrical Features of the Body Surfaces of Catharisius Molossus Linnaeus and Their Fractal and Wettability", Master degree Dissertation of Jilin University, 2002
[7] Herman, S, "The Wing of a Butterfly", Global Cosmetic Industry, 2002, 8, 32
[8] Bechert, D.W.; Bruse, M.; Hage, W.; Meyer, R. "Biological surfaces and their Technological Application – Laboratory and Flight Experiments on Drag Reduction and Separation Control", *AIAA-paper* 1997, 97-33426
[9] Wagner, P.; Fürstner, R.; Barthlott, W.; Neinhuis, C. "Quantitative assessment to the structural basis of water repellency in natural and technical surfaces", *Journal of Experimental Botany*, 2003, **54**, 1295-1303

Design and Nature II, M. W. Collins & C. A. Brebbia (Editors)